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ABSTRACT

A problem-solving method of teaching was used in the recitation sections of a freshmen chemistry course for science and engineering majors at Purdue University. The method was based on prior research which revealed that good problem solvers formed better representations and used heuristics more often than poor problem solvers. Consequently, the use of heuristics (such as working backwards and trial and error methodology) was stressed throughout, as was the use of three different modes for representing (understanding) the problems, namely, the macroscopic, microscopic, and symbolic levels. Furthermore, a three-phase approach to solving problems (planning the solution, solving the problem, and reviewing the solution) was also presented. Both this teaching method and a more traditional method were used by two different instructors. In the traditional sections, instructors primarily reviewed assigned problems at students' requests. Instructors using the experimental method not only covered assigned problems but also some new problems. During the last 2 weeks of the semester, selected students were given a series of five problems to solve out loud. Transcripts of these interviews, together with students' written work, served as the protocols which are currently being analyzed. (Author/JN)

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THE EFFECT OF A PROBLEM-SOLVING TEACHING METHOD ON STUDENT PROBLEM-SOLVING PROCESSES

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Abstract

A problem-solving method of teaching was used in the recitation sections of a freshman chemistry course for science and engineering majors at Purdue University. The method was based on prior research by Greenbowe and Nurrenbern which showed that good problem solvers formed better representations and used heuristics (general problem-solving strategies) more often than poor problem solvers. Consequently, the use of heuristics, such as working backwards and trial and error, was stressed throughout, as was the use of three different modes for representing (understanding) the problems: the macroscopic, microscopic, and symbolic levels. Furthermore, a three-phase approach to solving problems (planning the solution, solving the problem, and reviewing the solution) was also presented.

Both this teaching method and a more traditional method were used by two different recitation instructors during the fall semester of 1985. In the traditional sections, the instructors primarily reviewed the weeks' assigned problems at the students' request. In the experimental section the instructors covered not only the assigned problems but also some new problems under the direction of the experimental method.

During the last two weeks of the semester, selected students were given a series of five chemistry problems to solve out loud. Transcripts of these interviews, along with the students' written work, served as the protocols which are now being analyzed.

The Effect of a Problem-Solving Teaching Method on Student Problem-Solving Processes

After listening to three papers on spatial ability, you might be wondering why I am giving a talk on problem solving in this paper set. Actually, the way I view the first three papers is this: why were three papers on spatial ability allowed in a paper set on problem solving?

At an extremely superficial level, the answer is that we all work at Purdue University and we wanted to give a presentation together. A slightly less glib answer is that some chemistry problems problems (such as determining stereoisomers) certainly have some spatial component.

In fact, our research was actually being conducted as two separate groups. Dr. Bodner's students were studying spatial ability, and Dr. Herron's students have been looking at problem solving. But as our research progressed, and we started to compare our results, we came to realize how closely related the implications of our studies actually were.

The first substantial hint of this relationship came from the finding that spatial ability correlated with stoichiometry problems about as well as it did with crystal structure problems (Carter et al, 1985). An initial explanation was given in terms of the "disembedding" ability required for solving both the FASP test items and chemistry word problems. This idea has been refined as the concept of "cognitive restructuring," a holistic stage which is useful in both spatial and verbal problems (Bodner and

McMillen, 1985). You will want to keep this concept in mind as I talk about the problem solving that I have observed in general chemistry students, especially when I talk about problem representation.

We have adopted a definition of problem solving which you have already seen [Slide 1]. This definition is one which is widely used by researchers in mathematics education. What is interesting about this definition is that the burden of proof of being a problem is put on the solver, not on the problem.

You can see two examples on the next slide [Slide 2]. The first item is generally not a problem for Purdue's Chem 115 students. They generally know which two numbers to subtract when they see this statement, although they may act as if they cannot do this when they see it in the lab! The second item is almost always a problem for Purdue freshmen. At the very least, they will have difficulty deciding whether or not to take into account the dissociation of water. By using the same terminology presented in a previous paper, we will call the first task an exercise; the second, higher-level task is a problem.

Some research on this type of chemistry problem solving has already been done. Nurrenbern (1979) found that high school students had memorized some information about stiochiometry problems, but they could not apply the information to the real world; the students would manipulate symbols rather than ideas. Greenbowe (1983) found that two of the distinguishing characteristics between expert and novice problem solvers were the richness of the experts'

representations and their greater use of heuristics. Our subsequent study made use of these findings in devising a plan for helping students become better problem solvers.

First, let's look at heuristics [Slide 3]. A heuristic is best understood when it is contrasted with an algorithm. When a student chooses and correctly executes an appropriate algorithm, he will always get the right answer. An algorithm is usually associated with an exercise or exercise-template (the type of exercise where the words are the same, but the numbers were changed to mislead the innocent). Use of a heuristic does not necessarily lead to an answer, but it gives the solver a start. Heuristics have wider applicability than algorithms and are usually associated with problems.

Some common heuristics are shown on the next slide [Slide 4]. These strategies are useful devices to try when a solver gets stuck. Sometimes they can be used to decide which step to take next in the solution; they may also be used in the more basic step of understanding the problem.

This brings us to the topic of representation (or understanding). Greeno (1978) has proposed three criteria for judging the adequacy of a representation: correspondence, coherence, and connectedness [Slide 5]. While these are useful for a researcher, these criteria are not specific enough to use with a learner.

Hayes and Herron have provided two practical guides for building representations. Hayes (1981) has specified exactly which parts of a problem need to be represented [Slide 6]. Herron (1983)

has suggested that chemists can operate at three levels: a macroscopic level involving things that can be sensed, a microscopic level of atoms and molecules, and a symbolic level which can represent happenings at the other two levels.

These ideas have influenced our model for teaching problem solving, as you will soon see. First, I want to remind you of the problem solving sequences of Polya and Hayes you have already been shown [Slide 7]. Our model [Slide 8] has combined several steps into only three phases of planning, solving, and reviewing. The influence of Hayes and Herron can be seen in the questions listed under the planning phase. No question are listed under the solving phase. Heuristics are intended to be used here; the choice of heuristic depends on the solver and the problem.

We used this model for teaching problem solving (the "experimental" method) in four recitation sections of Chemistry 115 at Purdue University during the Fall, 1984 semester [Slide 9]. You may recall that Chem 115 is our mainstream course for science and engineering majors. Purdue's recitations are designed for a maximum of twenty-four students. By the end of the semester, about twenty students remained in each section. The "control" method of teaching involved a question-and-answer session initiated primarily by the students.

A think-aloud interview was used for evaluating the effect of the instruction on the students' problem solving processes such as representation and heuristics. Thirty students were randomly selected to be interviewed during the last two weeks of

class. Only twenty-nine students actually showed up, since one refused to be interviewed. During the interview, each student was given two warmup tasks [Slide 10], followed by five chemistry problems [Slides 11-12]. The chemistry problems had been pretested before Thanksgiving with students from other sections to verify that they were indeed problems (and not exercises).

The student interviews were tape-recorded and have since been transcribed. The transcriptions along with the student work on each problem constitute the protocols which are now being analyzed. A coding form of the students' problem-solving processes will be part of the analysis, but this has not yet been carried out.

The part of the analysis which has now been completed is a qualitative look at how the problems were solved by all the subjects. Since the first problem has an aspect requiring spatial ability, this is the problem that I will describe.

The next slide [Slide 13] shows some of the patterns that can be seen in the twenty-nine student protocols. From the information in the original problem, it can be readily determined that there are five pairs of electrons surrounding the central atom. From the resulting base structure of trigonal bipyramid, two bonding electron pairs give a linear arrangement of atoms. Only eight subjects correctly reasoned out the linear structure; five more were able to identify the trigonal bipyramid structure.

The second table shows that many subjects tried to determine either the Group number of X or the entire number of electrons

present. Only three of them were able to determine the linear structure. The next slide [Slide 14] shows the difference in the work of these subjects. Subject #15 drew the picture that you see. He called it "trigonal planar," but he reasoned as if he knew what the structure was but merely had an incorrect name for it. Subject #41 counted fifteen electrons, but he distributed nineteen electrons around the molecular ion. He found a 109.5° bond angle, based on a tetrahedral base structure. Those who incorrectly solved the problem like this seemed to misidentify the problem as a type they had solved before.

At least three of the subjects appeared to have a correct structure in mind but were unable to solve the problem. They made statements like this: "If I can remember what type of structure this is, I can figure out the bond angles." The successful solvers were able to make use of their microscopic representation; the unsuccessful solvers of this type were using the drawing only as a means of retrieving further information, not as a basis for reasoning out the answer.

The ultimate goal of this study, when the coding of the protocols has been completed, is to determine aspects of the problem-solving processes were affected by the teaching method. By making use of the qualitative data which were also obtained, we should be able to see which parts of the teaching method were effective and perhaps have a glimpse of how the ineffective parts could be improved.

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WHAT IS A PROBLEM?

Whenever there is a gap between where you are now and where you want to be. . .

. . .and you don't know how to find a way to cross that gap. . .

. . .[then] you have a problem.

Hayes

WHAT IS PROBLEM SOLVING?

Problem solving is what you do when you don't know what to do.

Wheatley

ARE THESE CHEMISTRY PROBLEMS?

A solution of sodium hydroxide (0.7500 M) is being used to titrate 25.00 ml of hydrochloric acid (unknown concentration). If the initial buret reading is 5.24 ml and the final buret reading is 33.80 ml (when the endpoint is reached), what volume of sodium hydroxide has been added to the acid?

Calculate the pH of a 1.7 x 10-4 M solution of a monoprotic acid HX. The acid dissociation constant K_a for HX is 1.0 x 10-10.

ALGORITHM

An algorithm is a clearly-defined series of steps or a pathway which inexorably leads to the solution of the question at hand if it is executed correctly.

HEURISTIC

A heuristic . . . is a rule of thumb, strategy, trick, simplification, or any other kind of device which drastically limits search for solutions in large problem spaces. Heuristics do not guarantee optimal solutions; in fact, they do not guarantee any solution at all.

HEURISTICS

Assume an answer---then test it

Change the problem into a related problem
- ---try an easier problem
- ---try a similar problem
- ---try a harder problem

Draw a diagram

Make a table or a list of the important information

Try setting a subgoal

Work backwards from the goal to the initial state

Look for a pattern

Write an equation---
- ---a chemical equation
- ---an algebraic equation

REPRESENTATION

. . .is the solver's mental reconstruction of a problem. A solver forms a representation of a problem in order to **understand** it.

CORRESPONDENCE

how accurately the representation matches the problem

COHERENCE

degree of internal consistency of the representation

CONNECTEDNESS

the use of information not specifically implied by the problem

REPRESENTATION:

(Understanding)

Parts of a problem that need to be represented:

1. The goal
2. The initial state
3. The operators
4. The restrictions on the operators

(from Hayes)

PROBLEM SOLVING SEQUENCES

According to: HAYES (Psychologist)	According to: POLYA (mathematician)
1. Finding the Problem.	
2. Representing the Problem.	1. Understanding the Problem.
3. Planning the Solution.	2. Devising a Plan.
4. Carrying out the Plan.	3. Carrying out the Plan.
5. Evaluating the Solution.	4. Looking Back.
6. Consolidating Gains.	

MODEL FOR TEACHING PROBLEM SOLVING

Planning

What do I already know?

What else do I know?

What am I looking for?

What does this look like?
---at the macroscopic level
---at the microscopic level

Can I draw a picture of it?

Can I symbolize it?

Solving

Reviewing

Can I estimate my answer?

Does my answer make sense?

Can I work this problem another way?

Is there another problem I could work this way?

EXPERIMENTAL DESIGN

		INSTRUCTOR	
		Margaret	Cathy
TIME OF RECITATION	8:30	Experimental	Control
	10:30	Control	Experimental

INTERVIEW WARMUP PROBLEMS

Warmup Problem #1. Cathy knows French and German, Sandra knows Swedish and Russian, Cindy knows Spanish and French, and Paula knows German and Swedish. If French is easier than German, Russian is harder than Swedish, German is easier than Swedish, and Spanish is easier than French, which girl knows the most difficult languages?

Warmup Problem #2. Copy the word sentence on your white sheet of paper. If the word sentence contains fewer than nine letters and more than three vowels, circle the first vowel. Otherwise circle the consonant which is farthest to the right in the word.

CHEMISTRY INTERVIEW PROBLEMS

Problem #1. The ion XF has three pairs of nonbonding electrons. Predict the size of the bond angle in this molecule.

Problem #2. Assume that the ionic radius of Cl^- is 0.181 nm. Consider a cubic closest-packed structure of Cl^- anions, in which all the anions are touching. Find the radius of the cation that just fits into the octahedral hole in the center of this lattice of anions.

Problem #3. Consider the following arrangement of interconnecting flasks. Assume that the temperature does not change and that the volume of the connecting tubing is negligible. What would be the final pressure after the stopcock is opened?

CHEMISTRY PROBLEMS (Cont.)

Problem #4. A certain compound consists of carbon, hydrogen, and chlorine only. If the ratio of hydrogen atoms to carbon atoms is 2:1 and the compound consists of 62.7% chlorine by weight, what is the empirical formula of this compound?

Problem #5. Cupric oxide, CuO, and cuprous oxide, Cu_2O, can both be reduced to metallic copper by passing hydrogen gas over the hot mixture according to the following reactions:

$$CuO + H \rightarrow Cu + HO$$

$$Cu_2O + H \rightarrow 2Cu + HO$$

A 1.00 gram mixture of cuprous oxide and cupric oxide is quantitatively reduced to 0.839 grams of metallic copper. What is the mass of CuO in the original sample?

PROBLEM 1

Predict the size of the bond angle of XF_2^-.

ANSWERS

8	Correct
2	Trigonal bipyramid structure used Incorrect placement of fluorines
3	Trigonal bipyramid structure used Angle wrong or not determined
16	Other

METHOD

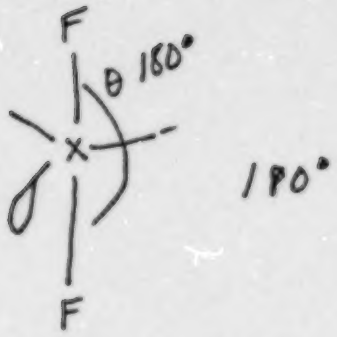
14 students tried to determine which group X was in or tried to determine the total number of electrons available

3	Correct answer
4	Identified trigonal bipyramid Incorrect angle
7	Did not even identify trigonal bipyramid

Slide 14

Subject #15

Problem #1



Subject #41
Problem #1

$|\underline{\bar{F}} - \underline{\dot{X}} - \underline{\bar{F}}|$

14 - 41 = 15

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